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COMBUSTION ENGINE PISTON MODIFICATIONS FOR BETTER PERFORMANCE IN UAV APLICATION

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Abstract

The issues described in the article are largely an overview and explanation of the functions of various modern modifications to internal combustion engine pistons, which significantly increase the performance and reliability of current power units with a minimum amount of technical implementation. Especially the modification in the form of gasporting can indicate the direction that will soon be possible to take when modifying engines.

Keywords

Unmanned aerial vehicle, piston ring, optimization

1. Introduction

With recent growth in UAV sector, UAVs are progressively used more than ever before. With growth of UAV use is closely tied growth of possible uses of such aircraft. Missions conducted by any aircraft put requirements on the aircraft engine. Electric motors are still not applicable for bigger unmanned aircrafts. Therefore is still important to use piston engines with better performance/weight ratio.

These days, society is working to make every sector more efficient. This is particularly evident in the transportation sector, where hybrid and particularly electric vehicles are being pushed. Low thermal efficiency is the main drawback of internal combustion engines. We shall discuss several technologies, though, that can boost the efficiency of internal combustion engines and, consequently, hybrid motors.

2. Piston ring

Accordin to (JE Auto – Blog, 2025) a piston is a part that allows us to drive a variety of devices by transferring the force produced by combustion to other parts of the rotating assembly. However, the internal combustion engine would operate very poorly and have an efficiency that would be very near to very low if we only had the piston. A significant pressure leak via the space between the cylinder and the piston would be the cause. They would encounter an issue when the piston began to rub against the cylinder wall, and the resulting friction would heat up, expand the piston, and cause a critical failure when our engine seizes. This would happen if someone proposed that we make the given piston with smaller tolerances in order to close this gap. We need a seal of some sort since we don't want this. Rubber and other organic materials were tested in the first internal combustion engines, but the high temperatures produced by the fuel-air mixture's combustion quickly degraded the sealing material. These sealing rings were continuous and single piece. It seemed sense to use gray cast iron. Making them continuous will result in the same issue as having too-low tolerance pistons in the cylinder. As a result, the piston ring needs to be made to look like the letter C. Nevertheless, this design leaves a gap that allows some expanded gases to escape. The specified piston ring will expand while in operation, and the gap will narrow but not completely vanish. Because of this, two so-called compression rings are used in the majority of internal combustion engines.

Cast iron rings are still used in many engines today. The material's insufficiently high hardness is a major drawback for them. Combining them with coatings of chromium elements can boost the contact surface's hardness by up to three times. Drawback of this is that it prolongs the break-in period, during which the rings adjust to the piston's form. The fragility of cast iron rings, which made installation extremely difficult because the mechanics had to be extra cautious to prevent the rings from breaking, is another reason they were discontinued. The piston rings' size, which were typically 2-3 mm thick, are the last explanation. Because of this, they produced more friction and consequently more losses than contemporary piston rings, which are, as stated in (Saccone, G. et al,2021), composed of 1-2 mm thin steel and have ceramic coatings applied to their surface that have a low friction coefficient and high hardness.

Another crucial element is the operation of the piston rings. The piston rings expanded up and had a wider diameter in the relaxed position than the cylinder bore when the piston was removed from the cylinder, as many readers who have ever disassembled an engine may have observed. Many people think that the material's elastic strength is what causes the piston rings to seal as described. This is a reasonable assertion, though. The expansion of the gases in the combustion chamber generates the force acting on the piston ring. When the pressure reaches the piston ring, it travels around the piston wall and acts from the upper side of the ring, ensuring tightness against the lower edge of the piston ring groove, while also pressing on it from the inside of the piston, ensuring tightness against the cylinder wall.

Figure 1. A cut of the piston together with the piston ring, engine P65, we would like to draw attention to the minimum distance between the piston ring and the upper edge of the groove

3. Gasporting

Since we are already familiar with the fundamentals of piston devices, we would like to expose you to the ones that were utilized in engine plants to improve tightness efficiency. This is referred to as gas porting, when attempting to increase the pressure acting on the piston ring. We differentiate between two fundamental forms of gas porting: vertical and horizontal.

A drilled holes in piston sits between the inside of the top piston ring's groove and the combustion chamber's surface when vertical gasporting is used. Because of this, there is less resistance as the pressure from the combustion chamber travels to the rear of the ring. This approach, however, has a number of drawbacks. The first is that sludge produced during engine running clogs these holes. As a result, they work well with engines that require little maintenance. An further drawback is the ringland's weakening in the piston's upper section, which, when combined with detonations, may rupture and result in a catastrophic engine failure.

According to (Micah Wright, 2022) the so-called horizontal gasporting is the second kind of this technology. These are tiny notches that run parallel to the piston ring groove. They facilitate the easier penetration of the required pressure behind the piston ring and are situated on the upper side of the piston ring groove. Similar to vertical gasporting, this kind also somewhat weakens the ringland. The piston can tolerate these locations even in the event of detonations, and cracks shouldn't appear. Although soot is an issue with this approach as well, it is not as bad as with vertical gasporting. Given these facts, it is reasonable to wonder why vertical gasporting is employed when horizontal has so many benefits. Vertical gas porting increased effectiveness of gas penetration behind the ring. Vertical gas porting is utilized in special engines with service intervals measured in hours.

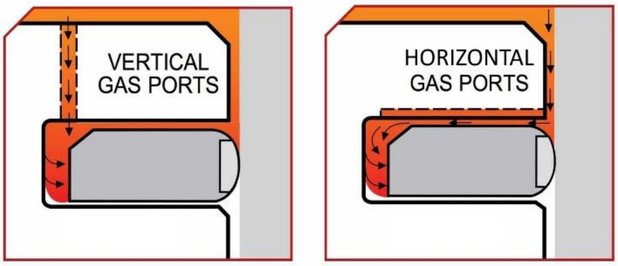

Figure 2. Demonstration of the functionality of vertical and horizontal gas porting

According to (Aeroplane Tech, 2024) a hybrid of both technologies is also available, in which the piston's notches line up with the piston wall's notches that make contact with the cylinder. This is known as vertical-horizontal gasporting, and it should take advantage of both methods' benefits. It is evident from this data that accurate tools are necessary for machining, which will raise the cost of manufacturing individual parts.

Gasporting can be accomplished on an engine without this technology, though. These unique piston rings function similarly to horizontal gasporting and have grooves carved into them. The reduction of sludge is their greatest benefit. Unless it has a lock, as in two-stroke engines, the piston ring is always moving in its groove. Its continuous motion causes the sludge to be mechanically removed from its surface. The ability of engine oil to effectively remove dirt from iron surfaces is another feature that helps prevent sludge.

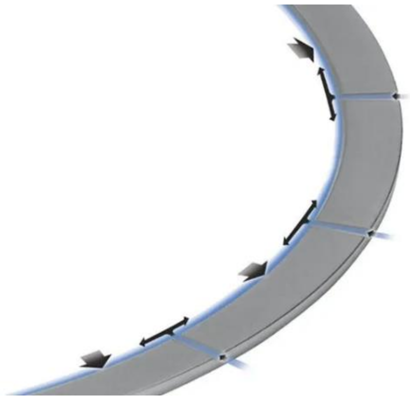

Figure 3. Demonstration of the functionality of a gasporting piston ring

However, when in operation, piston rings create a significant amount of friction. Potential method of sealing the combustion chamber without causing too much friction exist. This is the process of applying a labyrinth seal between the piston's top and upper ring. The idea behind these shallow grooves is to produce turbulence as gases enter, which gives the gases resistance. As a result, the labyrinth should form a partially frictionless sealing barrier. As a result, there is less pressure on the piston ring, which lowers friction. If gasporting is used, friction should be reduced and the sealing effect increased.

The primary element that transfers heat from the piston to the cylinder walls is the piston rings. This implies that there will be less heat transmission if the piston rings are thinner. Better oil spraying from the lubricating system or enriching the fuel-air mixture are two ways to address this issue; nevertheless, doing so would lead to incomplete combustion, increased sludge production, and, most importantly, a larger percentage of emissions. Enhancing the cooling system's ability to dissipate heat from the cylinder walls is the answer. The usage of a cast iron cylinder liner, which has good qualities in retaining geometric dimensions throughout temperature cycles, is the issue with earlier engines. Another benefit is that, because the bonded liners are between 2 and 7 mm thick, the engine can be repaired in the event that the top layer is damaged. Unfortunately, this is a drawback because their thermal conductivity is around 30% lower than that of aluminum. In order to improve heat dissipation and increase cooling efficiency, different high-hardness coatings were applied to engines with a rake of 0.05-0.15mm of applied material. This allowed engines to run at a stoichiometric ratio for longer periods of time without the need for enriching the mixture to cool. Additionally, these coatings have less friction, which lowers friction and, consequently, temperatures on vital parts like piston rings. To a specific degree and depth of damage to the cylinder surface, a new coating can be applied to an engine cylinder. Additionally, in correspondingly tiny craters, the coatings produce microscopic surface roughness that keeps oil on the cylinder surface throughout engine operation. The so-called honing, which produces a much rougher surface with continuous depressions where oil is stored, was required for cast iron liners. This is among the elements that significantly influences the friction that results.

4. Application of gasporting

We made the decision to test the P65 engine in light of this information. In the 1980s, in what was then Czechoslovakia, this two-stroke car engine was frequently utilized as an engine for hang gliders or ultralight aircraft, as was stated in (Longauer, Čerňan, 2024). It should be mentioned that the engine's primary components remained nearly unchanged from its development in the 1950s until the end of the 1980s. Three 2mm cast iron piston rings are part of the original design. Critical locations are not perfectly lubricated because the engine is lubricated using a fuel-oil combination. The main issue, though, is that while the outer rings are suitably lubricated, the middle ring is not. This lowers the engine's efficiency and service life by increasing friction. The testing aims to apply gasporting to the piston ring's upper groove and alter the piston to operate with just two piston rings.

Before we start modifying the engine in special design described in (Lubják, Čerňan, 2024), we need to find out the critical engine data. We will start by finding out what pressure the individual cylinders have. The test was done at operating temperature after adequate use of the engine. The speed with the starter turned on was kept at 380-400 rpm. During testing, the spark plugs were removed from both cylinders and the throttle was in the open position to avoid unnecessary pumping losses. The engine was revved for 10 seconds and the achieved value was subsequently read. Cylinder number one reached a value of 6.1 ATM, cylinder number two reached a value of 5.9 ATM. Subsequently, a series of test runs were made over a longer period of time during which we recorded consumption and engine head temperatures.

After the initial testing, we disassembled the engine and marked the individual components to avoid part changing. After removing the piston rings from the piston, we started modifying the pistons so that they work with only two rings. Someone might say that it is enough to remove it and there is nothing more to solve. However, the problem arises that through the given groove, fresh mixture can penetrate through the transfer channels into the exhaust channel and vice versa. Therefore, we need some type of barrier to prevent this gas exchange from occurring. We solved this problem by drilling two 1.8mm holes approximately 3 mm from the edge of the exhaust channel on both sides of the piston. Then, we cut rollers of the correct length from 2mm drills, which we gently tapped into the drilled holes. To secure these rollers, we tapped the lower part of the ringland directly below these rollers. Subsequently, the excess material was removed from the rollers, thus achieving adequate sealing in the given locations.

This modification will convert 3-ring pistons to 2-ring ones. Another modification is to create a gasporting on the upper piston ring groove. First, we mark the calculated equal distances with a marker. Then we have two options for creating the notches. Either we take a drill with an adequate drill bit and carefully drill out the excess material using a jig. In our case, we used a milling machine with which we carefully created the aforementioned notches by hand. However, it should be emphasized that if you create these grooves at home, you must be especially careful not to damage the lower edge of the piston ring groove. If it is damaged, repair is almost impossible and the damage may cause a leak in the upper piston ring, which would ultimately mean that we have done a counterproductive job. After completing all the modifications, we thoroughly clean all components from aluminum shavings and other material. When assembling, we ensure proper lubrication of individual components to prevent premature damage.

After completing the engine, we performed a rotation test without the spark plugs inserted and were quite surprised that the engine could only be turned over with a screwdriver with an extension, since before that the engine could only be turned over using a ratchet. After approximately 15 hours of operation, we performed a cylinder pressure test, making sure that the test conditions were identical. During testing, we found that cylinder number one reached a value of 6.1 ATM, cylinder number two reached a value of 6.2 ATM. Considering that the engine uses 1/3 fewer compression piston rings, it is surprising that the pressures in the cylinders increased. We observed approximately 5% lower consumption when using the engine than during test runs before the modifications. The head temperatures were kept at the same temperatures as before testing. Considering the location of the temperature sensor, it is unlikely that the temperature reduction on the cylinder walls had an adequate effect on the head temperature around the spark plug. Also temperature sensor in exhaust system will be used as described in (Koša, Čerňan, 2023) to improve air/fuel mixture and get lower carbon monoxide and hydrocarbon content in exhaust gasses. Policy of carbon neutrality will lead our effort to use also new types of fuel, as stated in (Valášek, Čerňan, 2023). Here the optimal function of piston rings will be crucial for good performance of the engine.

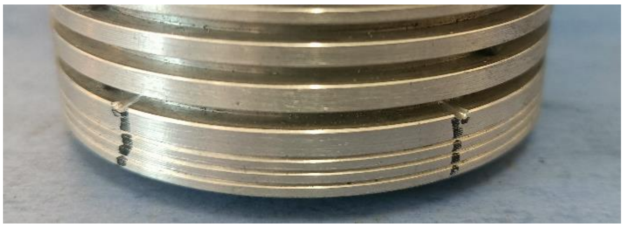

Figure 4. P65 engine piston after the mentioned modifications

5. Conclusion

Our experiment shown that it is possible to boost the efficiency of older engines by utilizing modern technologies. We can save resources during routine maintenance because of these fairly straightforward changes.

Acknowledgement

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AERODYNAMIC OPTIMAZATION OF LONG ENDURANCE UAV WING

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Abstract

With recent growth in UAV sector, UAVs are progressively used more than ever before. With growth of UAV use is closely tied growth of possible uses of such aircraft. Missions conducted by any aircraft put requirements on the aircraft itself. This leads to necessity of optimization of aircraft for specific mission profile to maximize its mission efficiency. This article focuses on optimization of UAV wing for long endurance flight.

Keywords

Unmanned aerial vehicle, aerodynamics, optimization

1. Introduction

The UAVs historically were mainly used in military applications. Nowadays however, UAVs are progressively used more in civilian sector as well. Many of such UAVs are rotorcrafts which are cheap to produce and have advantage in the ease of control. Fixed wing UAV used in civilian sector also exist. The use of UAV in civilian sector is quite wide encompassing uses such as aerial photography, aerial surveying, atmosphere sampling and many others (Austin, 2010). The advantage of fixed wing UAVs in comparison to rotorcraft UAVs is speed, range and carrying capacity (Heaphy et.al., 2017). Fixed wing UAVs are therefore optimal platform for long endurance flights. Such flights may be needed during long term atmospheric surveillance (Austin,2010). On the other should the UAV be designed with the speed in mind, an UAV for short range quick mission profiles can be created. The aerodynamic design of UAV similar to manned aircraft has to adjust based on the mission requirements. This means that based on a mission profile a specialized UAV will have its own advantages and disadvantages (Gudmundsson,2014). For example, an UAV designed for long range operations and high endurance will use high aspect ratio wing to improve aerodynamic efficiency of the UAV. This however leads to increased drag due to increased frontal cross-section. On the other hand, an UAV designed for higher speeds will use sweep of a wing to reduce its drag making it easier to reach higher speeds. This, however, reduces the lift of the wing leading to lower total aerodynamic efficiency (Bertin, 2009). In this article we will take closer look at design of wing for long endurance aircraft.

2. Wing design

Wing design of UAV is very important part of entire design of UAV. It is responsible for big part of UAVs aerodynamic performance. Wing design also influences the stability of the aircraft and its controllability. It is also important from structural point of view. Should the wing design use airfoil that is too thin it can complicate construction process (Gudmundsson, 2022). It also reduces internal volume of the wing which can be used for installation of electronics, fuel tanks and other systems needed in UAV.

2.1 Long endurance UAV wing design

Long endurance UAV wing design must maintain as high aerodynamic efficiency as possible. This leads to high lift generation at relatively smaller drag which helps with increase of total range of flight. To achieve this a high aspect ratio wing is generally used. (Ma et.al., 2024). These wings are susceptible to wind gust due to their large total area. To help stabilize the aircraft a wing dihedral angle can be used (Gudmundsoon, 2022). Aerodynamic performance can be furthermore increased by targeting ideal elliptical lift distribution. This can be achieved in multiple ways. In theory easiest way is to use elliptical wing. Elliptical wing from aerodynamic point of view is most efficient due to ideal lift distribution which leads to reduction of induced drag. It also improves stall characteristics of wing by stalling everywhere equally (McCormick, 1979). This however is not the best solution from structural point of view as constructing an elliptical wing is harder than regular straight wing. Therefore, to get as close to elliptical lift distribution different approaches are used in practice. Tapered wing creates similar lift distribution to elliptical wing whilst being easier to construct than elliptical wing (Güzelbey et. al., 2019). Should however a constant wing chord be needed on the entirety of wingspan wing taper cannot be used. In the case neither of these two wing platforms can be used a wing twisting can be used to adjust lift distribution. Geometrical wing twist can be used to adjust the lift distribution by change of angle of incidence leading to increased lift generation. It is therefore possible to increase lift at the wing root and gradually decrease it until wingtip. By locally increasing angle of attack however drag increases as well. This is due to increase in frontal cross section of the wing (Prajwal et. al., 2024). This may seem as counter intuitive as with increase of lift there is also associated increase of drag and therefore the increase in the aerodynamic efficiency should be non-existent. However, lift generally increases more with increase in angle of attack than drag is and therefore this adjustment often leads to improvement of aerodynamic efficiency at 0 degrees of angle of attack. Additionally, by locally increasing angle of attack a local stall angle also changes. This can be easily explained on example of wing with stall angle of 15 degrees of angle of attack. This wing as expected upon reaching 15 degrees of angle of attack would stall. Now should we adjust this wing by introducing a geometrical wing twist in which a wing root angle of incidence is 5 degrees progressively reducing to 0 degrees at wing tip. This wing now stalls earlier with first stall being at wing root at angle of attack of 10 degrees as local angle of attack of wing root is sum of angle of incidence and total angle of attack of the wing. This phenomenon can prove beneficial by inducing vibrations to fuselage indicating the loss of lift of the wing to the pilot (Prajwal et. al., 2024). It however is not ideal for aircraft which may experience sudden increases in angle of attack and quick changes in direction of flight. During such conditions a sudden loss of lift on wing can lead to loss of control of aircraft. Another way of changing the lift distribution without need of geometrical twist of wing is aerodynamical twist of wing. This is done by changing the airfoil in certain sections of the wing to change aerodynamic characteristics of wing sections and therefore adjust the lift distribution of the wing. This however can prove problematic especially if the airfoil shape is vastly different from each other leading to design and construction complications (Scholz, 2015).

3. Airfoil choice

Airfoil choice is very important part of wing design process. This is due to fact that airfoil choice is capable of heavily influencing the total aerodynamic wing performance (Gudmundsson, 2022). The best example of this would be comparison of symmetrical and asymmetrical airfoil. Using asymmetrical airfoil on regular straight wing leads to a wing with good lifting performance. This lifting performance is however only present in positive angles of attack. Should an aircraft using such wing find itself flying upside down, the wings lifting performance would drastically worsen. This is not the case for symmetrical airfoil which would have identical performance in both regular flight and flight upside down. Symmetrical airfoil however has worse aerodynamic performance than asymmetrical airfoil in regular flight as it needs higher angle of attack to generate same lift as asymmetrical airfoil does at 0 degree of angle of attack (Gudmundsson, 2022).

3.1. Long endurance UAV airfoil choice

Airfoil choice for long endurance UAVs follows same basic principles as wing design for these UAVs. That being that the airfoil should allow to reach as high aerodynamic efficiency as possible. This means that the airfoil must generate as little drag as possible whilst generating as high lift as possible. Due to expected low flight speeds for these UAVs a low Reynold’s number of airfoils can be used (Gudmundsson, 2022). These airfoils are specifically designed for flight at lower speeds. This allows for low drag generation and high lift generation even at low angles of attack. To increase a total lift generated by airfoil an increase in pressure fields generated by airfield may be targeted. This is usually the goal of laminar flow profiles. These profiles maintain laminar flow for longer percentage of airfoil chord length therefore increasing a total lift generated. The disadvantage of these profiles is that they must be always kept clean to maintain laminar flow around them otherwise the total lift generated lowers (Gudmundsson,2022).

4. Wing design process

Based on described requirements of long endurance UAV wing, a design process must considere the airfoil choice and design of wing geometry. In this article initial 3D model is created in Autodesk Inventor and subsequently tested in Ansys Fluent. Testing in Ansys Fluent provides necessary acting forces information.

4.1. Long endurance UAV design description

The long endurance wing design described as part of this article was designed as part of a project to create long endurance UAV for atmospheric surveying. Due to necessity of long endurance a high-wing half span of 2.85 meters. Total wingspan is 5.7 meters. A dihedral angle is introduced on the wing 0.9 meters from the wing root. This is done to improve the stability of the wing and to reduce the bending moment acting on the root of dihedral part of the wing. Wing chord is 0.305 meters. To improve stall characteristics an angle of incidence of 3 degrees is present at the wing root. This causes wing root to stall earlier warning the pilot of imminent loss of lift. Furthermore, this geometrical wing twist leads to improvement of lift distribution. It increases lift near the wing root and gradually reduces it to the wing tip. This optimization of lift distribution was chosen to keep the wing area as large as possible improving lifting capability of wing. The wing therefore meets basic design criteria for long endurance flight. The design of the wing can be seen in figure 1.

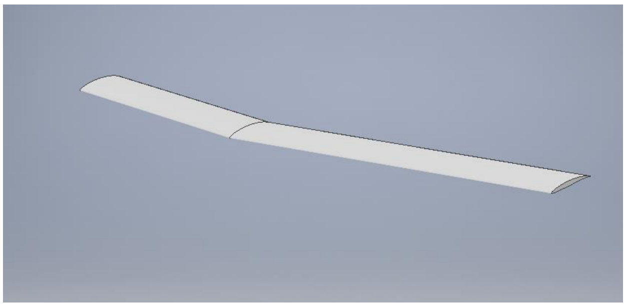

Figure 1. Proposed wing design

4.2. Wing airfoil choice

The most important factor in finishing the wing was airfoil choice. The use of low Reynolds number airfoils is possible as expected speed of flight sits in around 40-60 kilometres per hour. The Reynolds number at those speed ranges from 2.2×10^5 to 3.4×10^5. Another possible usable airfoil is laminar flow airfoil. By increasing area of low-pressure zone by use of laminar flow airfoil a high lift generation is expected. Series of models was tested as a part of design process with multiple airfoils being tested. The tested airfoils included:

- MH139
- Series of Modified NACA 4-digit airfoils
- Eppler E387

- Eppler E67
- Eppler E393

These airfoils were chosen based on their 0 degree angle of attack lift coefficient and drag coefficient. This was done to perform initial estimation of aerodynamic efficiency of the wing.

Table 1. Aerodynamic coefficients of tested airfoils

Airfoil	**Lift Coefficient**	**Drag Coefficient**	**Aerodynamic efficiency**
MH139	0.5	0.012	41.7
Eppler E387	0.4	0.0098	40.8
Eppler E67	0.4	0.013	30.8
Eppler E393	0.51	0.011	46.4
NACA modified series	~0.68	~0.05	13.6

The drag and lift coefficients for modified NACA series is not specific due to differences from each airfoil tested. The average values are instead present for all the airfoils tested. Despite the unexpectedly low aerodynamic efficiency of NACA series airfoils the resulting aerodynamic efficiency of the wing was one of the best. This may be caused by difference in measurement method used by application which was used to generate these airfoils.

Use of these airfoils allowed the wing to reach values of aerodynamic efficiency higher than 26 on average. There were however few outliners which reached values higher or close to 30. These were subsequently chosen for further testing and improvement. The airfoils in question are:

- NACA 4 digit (45xx) modified series
- Eppler E387
- Eppler E393

NACA 4-digit modified airfoils were modified in such a way as to increase the camber of trailing edge section of the airfoil. This adjustment increases lift generated by the airfoil. Additionally, a relatively high maximum camber of 4 % was used. This was again done to increase lift generation. To make the area of resultant pressure fields as large as possible the position of maximum camber and thickness of the airfoil is in its middle. This location causes the pressure to be minimal in the middle improving the pressure gradient of the airfoil. Improvement in pressure gradient results in increased area of lower pressure zone. This effectively creates a laminar flow airfoil. The disadvantage of this solution is increase of airfoil pitching moment as the centre of pressure moves more aft.

By adjusting the maximum thickness of airfoil there were totally 3 NACA 4-digit airfoils tested:

- NACA 4512
- NACA 4510
- NACA 4509

The best aerodynamic results of the wing were gained by use of Eppler E387 airfoil and modified NACA 4509 airfoil. These results will be further described.

4.3. CFD wing testing results

Series of models, differing by airfoil used, were tested in CFD environment of Ansys Fluent. The mesh of model consisted of fluid domain with body of influence around the wing. Additionally face sizing was added to the wing itself to improve accuracy of simulation. Both body of influence and face sizing were set to 0.005 meters. Volume meshing was performed in fluent mesher by use of poly-hexcore method. The testing was conducted with SST-ω viscous model. The NIST real gas model was used in simulation. This model uses fluid properties close to real life fluids, in our case air. The flow velocity was set to 14 m/s which is approximately 50 kph. The simulation iteration limit was set to 250, however convergence was reached before this limit in all cases. Two best results for simulated wings will be described below. The airfoils used in these models were Eppler E387 low Reynolds number airfoil and modified NACA 4509. The resulting acting forces on the wing are shown in table 1. Graphical comparison of results can be seen in figure 2.

Table 2. Force results of tested models

Airfoil	**Lift**	**Drag**	**Efficiency**
Eppler E387	45.82	1.45	31.55
NACA 4509 modified	58.87	1.85	31.82

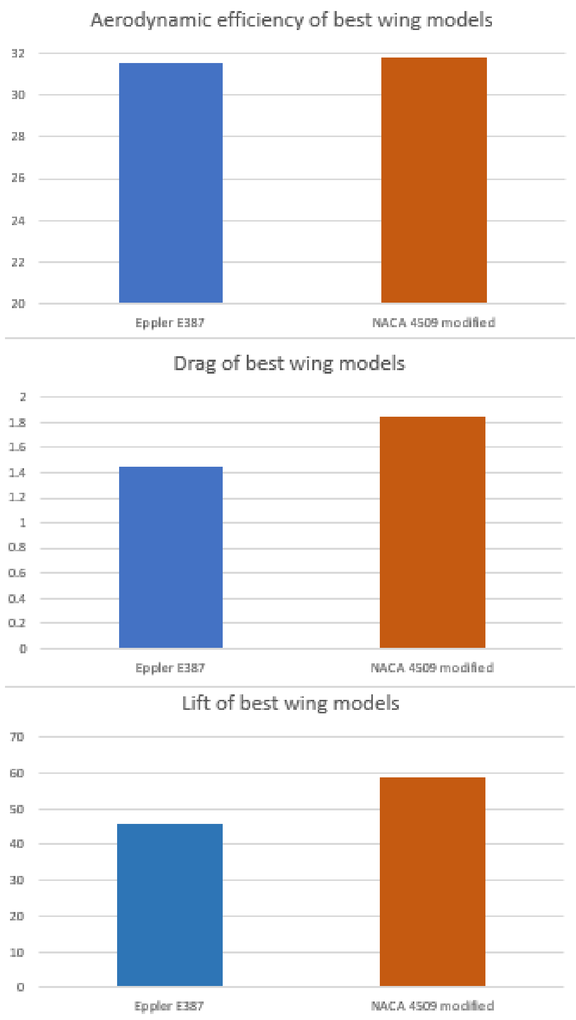

Figure 2. Graphical comparison of aerodynamic properties of wing models

From the gained forces aerodynamic coefficients can be calculated. Calculated aerodynamic coefficients are shown in table 2.

Table 3. Aerodynamic coefficients of tested models

Airfoil	**Lift Coefficient**	**Drag Coefficient**
Eppler E387	0.45	0.014
NACA 4509 modified	0.57	0.018

The gained results show that the aerodynamic efficiency performance of both models is practically identical. The percentual difference is 0.88 %. Bigger difference can be seen in drag and lift. The NACA 4509 modified airfoil generated more lift than Eppler airfoil. The total percentual difference between the two models in left generation was 28 %. The drag was also higher for NACA airfoil. The total drag difference was 27 %. The marginal gain in aerodynamic efficiency on NACA airfoil can be therefore explained by higher lift increase to drag increase. This change is however minimal and would have very little performance impact. Considering the efficiency is very similar a deciding factor in choice between these two airfoils would boil down to drag and lift needs. Should the final model of UAV prove to be heavier than expected a higher lift generation may prove beneficial. Additionally, by generating higher lift it is possible to lower the speed of flight of model whilst maintaining enough lift. By lowering the speed of flight, the drag reduces as well. Should a reduction in drag be more important than lift generation then Eppler airfoil is better choice due to having less drag than NACA airfoil. The difference in drag and lift of the airfoils can be described based on the velocity and pressure field acting on the wing. The pressure fields of Eppler airfoil can be seen in figure 3 and NACA airfoil in figure 4.

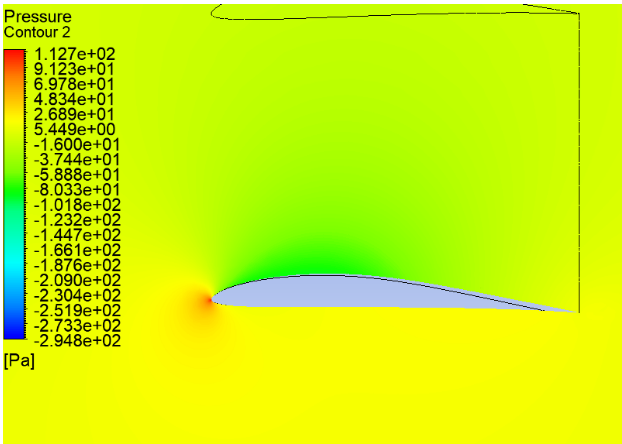

Figure 3. Pressure distribution of Eppler airfoil on wing model

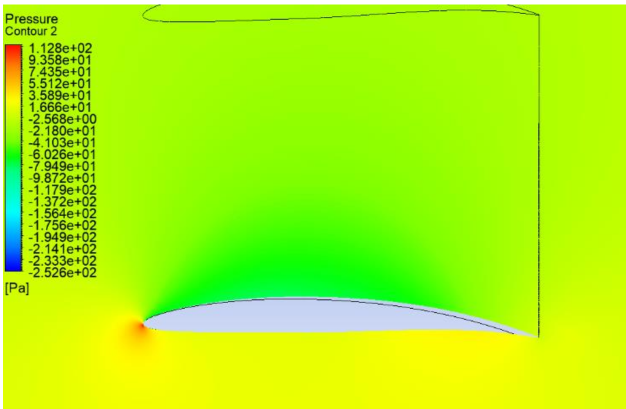

Figure 4. Pressure distribution of NACA 4509 modified airfoil

There are two important factors in terms of pressure distribution and that is size of the pressure field and pressure magnitude. In terms of pressure magnitude Eppler airfoil comes out on top reaching lower pressure on top of the airfoil. This peak of low pressure is however small in comparison to modified NACA 4509 which maintains the area of lower pressure on large part of its total chord. This is also supported by the velocity fields which can be seen in figure 5 for Eppler airfoil and Figure 6 for modified NACA airfoil.

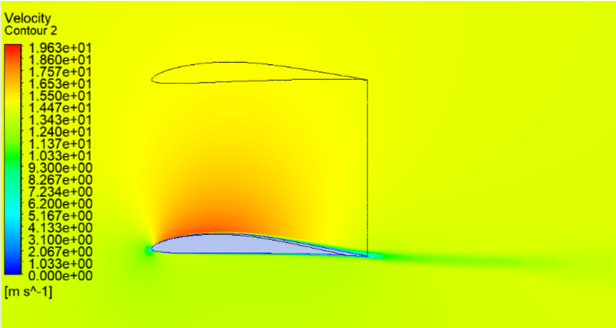

Figure 5. Velocity Distribution of Eppler airfoil

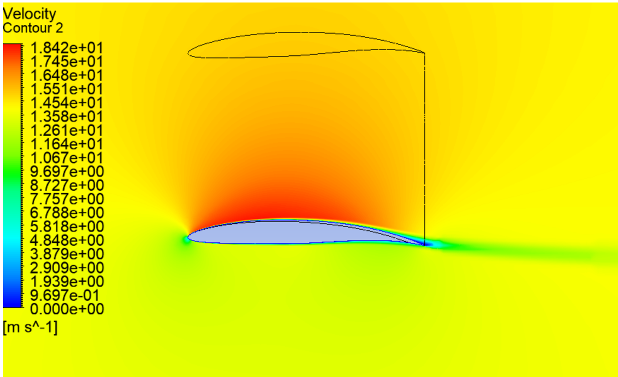

Figure 6. Velocity distribution of NACA 4509 modified airfoil

By comparing the velocity fields, we can see that average maximum velocity is maintained in larger area above NACA airfoil compared to Eppler airfoil. This is the reason behind the higher lifting capability of the airfoil. From the drag point of view the higher drag may be caused by the larger separation area behind NACA 2509 airfoil in comparison to Eppler which shows much smoother flow near the trailing edge of the airfoil. Additionally, by increasing the camber of trailing edge on the NACA 2509 airfoil there is a larger area of positive pressure near the trailing edge which can influence the drag of the model.

5. Conclusion

An initial wing design's aerodynamic properties were successfully optimized by aerofoil selection process. The initial average value of aerodynamic efficiency was around 26 with final aerodynamic efficiency of the wing was 31. This represents a 19 % improvement in terms of aerodynamic efficiency. The two best airfoils tested differed very slightly in area of aerodynamic efficiency. Their difference was however much more visible in terms of drag and lift. Therefore, the final choice of airfoil for wing boils down to priority of lift and drag requirements.

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FATIGUE IN THE AIR AND AT SEA: COMPARING IMPACT AND REGULATIONS IN AVIATION AND MARITIME TRANSPORT

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Abstract

Fatigue poses a significant threat to transportation safety across all modes of transport. This paper examines fatigue, its consequences, and the regulatory frameworks addressing this issue, with a focus on the aviation and maritime industries. A comparative analysis is conducted on differences in legislation governing maximum duty hours, mandatory rest periods, and the risks resulting from non-compliance. By highlighting regulatory differences and their implications, this paper underscores the importance of effective fatigue management to enhance safety in both sectors.

Keywords

fatigue, aviation, maritime

1. Introduction

Both the air and maritime transport operate in highly dynamic and demanding environments, where fatigue is a dangerous challenge. Crew members onboard maritime vessels live and work onboard ships 24 hours per day, often experiencing irregular and extended shifts in noisy and stressful conditions. Similarly, pilots and flight crews face long duty periods, circadian disruptions, and sleep deprivation, all of which impair cognitive function and reaction times. While fatigue is a natural consequence of such work environments, its effects can be severe, leading to reduced alertness, impaired decision-making, and an increased risk of accidents. Despite existing regulations aimed at managing fatigue, both industries continue to grapple with this issue, necessitating further research and enhanced preventive measures to ensure operational safety.

Comparing the impact of fatigue and the regulatory framework governing work and rest hours in aviation and maritime transportation is important, as both sectors are part of High Risk Industries (HRI) (Kandera et al., 2019), and both require high levels of alertness and decision-making. While fatigue poses a significant safety risk in both transport modes, the frameworks governing work and rest periods differ. An analysis of these differences can reveal potential gaps in existing policies and highlight opportunities for improving fatigue management and overall safety in both industries.

2. Fatigue, its impact on decision-making and task performance

Fatigue is a critical factor affecting decision-making and task performance across various sectors and industries, especially in safety-sensitive sectors like aviation and maritime transport. In the following chapters, the main differences effects of fatigue in aviation and maritime sectors will be analysed, highlighting its impact on safety and performance.

2.1. Fatigue in maritime

International Maritime Organization (IMO), specialised agency of the United Nations, dealing with safety-related issues, defines fatigue as "a state of feeling tired, weary, or sleepy that results from prolonged mental or physical work, extended periods of anxiety, exposure to harsh environments, or loss of sleep. The result of fatigue is impaired performance and diminished alertness" (IMO, 2014). Fatigue is widely defined as a complex issue in the shipping industry. In the past, factors such as behaviour, intelligence, training, motivation, and physical attributes were mistakenly supposed to protect seafarers from fatigue. This led to the underestimation of fatigue as a significant contributor to human error (IMO Guidance, 2006). However, recent research disproved this statement, pointing out to the significant effects of fatigue on performance and its role in maritime accidents. fatigue's effects on performance and its role in marine casualties.

The effects of fatigue in the shipping industry are often more severe and potentially fatal compared to other transportation sectors. Seafarers face harsh working conditions, including noise, vibration, heat, and adverse weather, while living and working away from home for extended periods—often up to six months. Additionally, the blurred boundaries between work and relax create a stressful environment. Moreover, the multinational crews add another layer of complexity, requiring individuals from different cultural backgrounds to cooperate in confined and demanding conditions (Galieriková, 2020). Furthermore, operational elements such as varying ship types, ship movement, and unpredictable sea conditions further contribute to the stressful environment onboard maritime vessel.

The effects of fatigue are particularly hazardous due to the specialised and high-risk nature of maritime operations, which demand constant vigilance and intense concentration. Fatigue is indiscriminate, affecting all workers regardless of skill, knowledge, or training (Interreg, 2018). The confined environment on ships amplifies the problem, as crew members often feel "trapped" in their workplace, with little separation between work and downtime. Research (Galieriková, 2019) highlights that fatigue is a significant contributor to maritime accidents. Based on Galieriková et al (2019), the lapses in judgment, resulting from fatigue, have led to high number of casualties. According to the study, the fatigue as the primary cause, resulted into 16% of accidents at sea and 33% share on total number of injuries onboard maritime vessels.

2.2. Fatigue in aviation

The International Civil Aviation Organization (ICAO), authority that set the minimum international standards for aviation sector, defines fatigue as: "a physiological state of reduced mental or physical performance capability resulting from sleep loss, extended wakefulness, circadian phase, and/or workload (mental and/or physical activity) that can impair a person's alertness and ability to perform safety related operational duties" (ICAO, 2016) (Kandera et al., 2019). In aviation, the fatigue can impair the ability to process and integrate various stimuli, including visual information (Russo, et al., 2005). It also increases the likelihood of reduced situational awareness, which can compromise flight safety in certain situations. This occurs because the brain struggles to merge information from different sources into a cohesive and relevant understanding of the aircraft's status (Keller, 2022).

Aviation accidents are relatively rare, but when they do occur, statistics indicate that human error is responsible for 80% of cases, with pilot fatigue contributing to 15-20% of fatalities. Fatigue impairs reaction time, concentration, and decision-making abilities, increasing the risk of errors. Additionally, there is the serious hazard - pilots unintentionally falling asleep mid-flight. A survey conducted by the British Airline Pilots' Association (BALPA) among 500 pilots revealed that 43% had fallen asleep in the cockpit, and alarmingly, 31% of them awoke to find their co-pilot asleep as well.

3. Regulations of working and rest periods

Regulations on working and rest periods in aviation and maritime transport are established in order to mitigate fatigue and ensure safety. In aviation, authorities like the ICAO, FAA, and EASA set limits on flight duty periods, minimum rest requirements, and fatigue risk management practices. The maritime sector follows regulations from the IMO and ILO, which define work-hour limits, mandatory rest periods, and crew fatigue management measures.

3.1. Maritime transportation regulations

The International Maritime Organization (IMO) and the International Labour Organization (ILO) set limits on work and rest hours as the foundation of fatigue risk management in the international shipping industry. Current regulations permit a maximum of 14 hours of work within a 24-hour period and up to 72 hours within a seven-day span (ILO, 2019). Additionally, IMO (2014) mandates minimum rest periods of no less than 10 hours per 24-hour period and 77 hours per week. Failure to comply with these regulations is a significant contributing factor to maritime accidents, as fatigue impairs cognitive function and decision-making abilities (Galieriková, et al. 2019). The physically and mentally demanding nature of maritime work, prolonged working hours make fatigue an ongoing and serious concern within the industry.

3.2. Aviation regulations

In aviation, regulatory bodies such as the European Union Aviation Safety Agency (EASA) and the Federal Aviation Administration (FAA) set specific limits on flight and duty times to ensure safety. According to EASA regulations, a pilot's flight time must not exceed 100 hours in any 28 consecutive days, 900 hours in any calendar year, and 1,000 hours in any 12 consecutive calendar months. Additionally, pilots are restricted to a maximum duty period of 60 hours in any seven consecutive days and 190 hours in any 28 consecutive days. The FAA imposes similar limitations, capping flight time at 100 hours in any 672 consecutive hours (28 days) and 1,000 hours in any 365 consecutive calendar day period. These regulations are designed to mitigate fatigue and enhance operational safety.

3.3. Comparation of regulations in maritime and aviation

Regulatory bodies in aviation and maritime sectors establish guidelines to ensure the safety and well-being of their respective crews. In aviation, ICAO, FAA and EASA set specific limits on flight time and mandatory rest periods to manage crew fatigue. Similarly, the maritime sector is governed by the IMO and ILO, which regulate working and rest hours to ensure the health of seafarers. The Table 1 shows the key differences between aviation and maritime regulations.

Table 1. Differences in regulations between aviation and maritime

Criteria	Aviation	Maritime
Maximum work hours (duty time)	**FAA**: **14 hrs for a single pilot** (under standard conditions). **2 pilots: 14 hrs** with relief, 16 hrs if flying >8 hours. **EASA**: **13 hrs** for a **single pilot.** **2 pilots**: **up to 16 hrs** depending on conditions. **ICAO: 12 to 16 hrs**. Recommends maximum duty time of 14-16 hrs based on operational scenarios.	**IMO: 12 hrs/24 hrs.** **ILO**: **14 hrs/24 hrs**.
Maximum flight/sea time	**FAA: 8 hrs in 24 hours.** **2 pilots: 9 hrs.** **EASA: 9 hours in 24 hrs** (or up to 10 hrs depending on circumstances). **ICAO: 8 to 10 hrs** for flight time **in 24hrs** (or extended based on conditions).	**IMO: 10 hrs per 24 hrs** (typically for **up to 2 consecutive days).** **ILO: 12 hrs per 24 hrs** for **up to 3 consecutive**

		days, 8 hrs for **rest.**
Minimum rest periods	**FAA**: **10 consecutive hrs** between duty periods (for flight attendants and pilots). **EASA**: At least **10 hrs** between duty periods. **ICAO**: **10 hrs** of rest required for flight crew.	**IMO/ILO: 10 hrs in any 24-hrs**, can be divided into 2 periods.
Break between rest periods	**FAA; EASA; ICAO**: - typically **12 hours** between duty periods (varies by operation).	**IMO**: **2 hrs** after 6 hrs of work **ILO**: not specified.
Maximum work hrs per 7 days	**FAA: 30 hrs** in **7 consecutive days.** **EASA: 60 hrs** in **7 consecutive days (single-pilot).** **2 pilots: 100 hrs.** **ICAO**: - **60 hrs** in **7 consecutive days.**	**IMO/ ILO: 72 hrs** per week.
Consecutive Work Days	**FAA, EASA, ICAO: 6 consecutive days, with 1 rest day** required **each week.**	**IMO/ILO: 6 consecutive days,** mandatory rest after.

Source: Authors based on data from IMO, ILO, EASA, FAA ICAO.

The aviation sector has stricter regulations than the maritime sector, particularly in terms of maximum work hours. Aviation authorities like FAA, EASA, and ICAO enforce tighter duty time limits, requiring pilots to rest more frequently due to the safety risks associated with fatigue in flight operations. In contrast, the maritime sector (IMO and ILO) allows longer work hours and more flexible rest periods because ships operate continuously over long voyages, and crews can rotate shifts to manage fatigue. The key difference is that aviation prioritises strict fatigue management due to the high risk of accidents from pilot exhaustion, while maritime regulations allow longer duty periods since ship operations are less time-sensitive and often involve multiple crew members sharing responsibilities.

4. Comparation of fatigue in maritime and aviation

Fatigue is a critical issue in both the aviation and maritime sectors, but its causes, effects, and regulatory responses differ significantly due to the nature of each industry. Aviation fatigue is often short-term and acute, primarily caused by jet lag, early departures, night flights, and irregular schedules. Pilots must remain alert for quick decision-making in high-risk situations such as take-offs, landings, and various emergencies. In contrast, maritime fatigue is more long-term and cumulative, developing over extended voyages due to long shifts, monotony, and extended time at sea.

In aviation, fatigue leads to impaired reaction times, reduced situational awareness, and poor judgment, which can be catastrophic given the rapid nature of flight operations. The aviation sector is highly regulated, with strict duty-hour limitations, mandatory rest periods, and fatigue risk management systems (FRMS) enforced by authorities like FAA, EASA, and ICAO (Gander, et al., 2011). By contrast, in maritime transport, fatigue builds up over weeks or months due to long working hours, minimal crew rotations, and disrupted sleep cycles (Galieriková, 2019). While maritime work does not demand the split-second reactions seen in aviation, slow decision-making and loss of concentration can lead to navigational errors, grounding, and collisions, sometimes with severe environmental and financial consequences (Akerstedt, 2000).

The work environment also shapes fatigue differently in both sectors. Pilots operate in a high-stress environment, facing intense workloads within short time frames, but they benefit from strictly regulated duty limits and scheduled rest periods. On the other hand, the seafarers experience long periods away from home, unpredictable work schedules, and extended exposure to noise, vibration, and harsh weather, which contribute to mental and physical exhaustion. Additionally, maritime regulations (IMO and ILO) addressing the issue of fatigue, are often less strictly if compared to aviation, with more flexible interpretations of work-rest balance.

While both sectors recognise fatigue as a major safety hazard, aviation regulations tend to be stricter and more proactive, while maritime rules offer greater flexibility but risk chronic fatigue accumulation. Addressing these differences requires industry-specific fatigue management strategies, ensuring that both pilots and seafarers can operate safely and effectively within their unique work environments.

5. Conclusion

Aviation and maritime transport are crucial for global connectivity but face serious fatigue-related challenges. Aviation crews manage irregular schedules, jet lag, and demanding flight operations, making fatigue a persistent safety risk. However, scientifically based scheduling and collaborative fatigue management can enhance safety. In maritime transport, long shifts and prolonged sea time lead to chronic fatigue, impairing cognitive function and increasing accident risks. Strengthening fatigue management strategies through better enforcement of rest periods, improved crew rotations, and enhanced monitoring can improve safety in both transport sectors. Addressing fatigue as a systemic issue rather than an individual responsibility will be key to maintaining efficient and secure operations in aviation and maritime transport.

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MUNICIPAL AVIATION FUNCTIONING AS ONE OF FUTURE TYPES THE AVIATION ACTIVITIES

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Abstract

There are represented the basic principles of municipal air transport within the metropolis. The main tasks of creating municipal transport are defined to further develop of aviation technologies for municipal economy and life support of the city and its air-transport system. In order to further development of aviation technology in the interests of the urban economy and life of the city, its air transportation system is necessary to decide three main objectives: development of aviation equipment and saturation of City Aviation park by light helicopters which will ensure solving of special tasks for the benefit of urban services, commercial transportation and air operations; development of urban aviation infrastructure, including heliports and helipads; the organization of safe use of the airspace over the city. The use of technology in aviation can be done while ensuring sanitary and environmental standards of environmental protection.

Keywords

aviation, aviation technologies, air transport system, municipal aviation

1. Introduction

Experience of the largest megacities of the world testifies to the widespread use of aviation and aviation technologies for municipal services and the viability of the city.

In the US and Western Europe are developed air transport system, which includes dozens of owners, operators, large and small heliports for helicopters, of which a significant part is private. These systems are developed according to plans of cities and regions. While the general trend to limit the activity of large airports, inside cities, and leaving the city limits, developed infrastructure heliports and helipads (Kharchenko & Alexeiev, 2009; Kharchenko et al., 2010)

Megapolis, as one of the greatest cities in the world, objectively feels the need to address a number of problems inherent in cities. Among them is need to increase the speed of response of city services (primarily law enforcement, emergency, fire, emergency medical care, etc.) in reduced bandwidth of highways and, as a result, difficult road traffic, especially in emergency situations. In addition, high population density and large number of functionally interrelated objects, greatly increase the risk of the consequences of industrial accidents, which requires continuous monitoring of environmental engineering and other technical systems and communications. The use of air assets (and, primarily helicopters) makes it possible to solve the above problems.

Solving the problem of aviation public transport (APT) has been made possible due to:

- The organization and the division of the Ukrainian airspace classes by order of the Ministry of Transport on 16.04.2003, № 293 (Ministry of Justice of 05.05.2003, the № 346/7667) "On approval of the Rules of aircraft operations and air traffic service in classified airspace Ukraine";
- The development of metropolis infrastructures, particularly in Kyiv;
- The development of robust aircraft capable of meeting the requirements for air transport, which is used in urban areas (Kharchenko, Alexeiev & Babeychuk, 2010);
- Development of scientific and technical means to ensure the monitoring of the state of the APT system in all the required aspects, namely: to ensure safety, ensure monitoring of compliance with the Rules of the Organization permit system, control environmental conditions, etc. out of sight of the radar supervisory and supervisory control using elements of CNS / ATM technologies in the lower airspace (Kharchenko, Alexeiev & Babeychuk, 2010).

Based on the technical possibility of implementing the APT system in the State Aviation Administration of Ukraine (SAA) by the the Administration of the President of Ukraine, the Cabinet of Ministers of Ukraine, Kyiv State City Administration and a number of air transport operators were sent reasonable inquiries about the possibility of the flights within the Kyiv municipality boundaries and to perform landings in urban areas. In the SAA the question is being discussed.

In addition, in the implementation of the APT system is interested a number of ministries and departments of Ukraine in particular for the implementation of medical aviation functions, search and rescue aviation, providing evacuation assistance to people from high-rise buildings in case of fire, law enforcement supervision, the transport of passengers, including VIP senior management country and city authorities.

The decision to implement the APT system will significantly accelerate the development of conceptual programs for the development of private aviation in Ukraine and related technological systems that can lead Ukraine on the high technological level of the organization and control of general aviation up to the statements of a number of international standards.

The positive effect of the implementation of AMT system is to increase the volume and circulating financial resources of the municipality, the municipal budget revenue and investment income from the provision of high-value services, the creation of a large number of jobs requiring highly skilled personnel.

Application of specific aviation equipment in municipal conditions can increase the interest of developers and manufacturers to fill this market by national developments[6,7].

2. Subject

The subject of this summary is to present the conceptual principles of the system of public transport aircraft, offering the concept of "Programme implementation system and the economic feasibility of its operation."

3. The concept of APT system organization

The main objectives of the APT system are:

- Development of air transport system of Kyiv;
- Improving the application of aviation technology in the interests of urban services and to ensure the city life;
- To ensure environmental safety in the city and its population, related to aviation activities.

AMT system structure consists of the areas:

1. The contour of consumers of aviation technology services.
2. The contour of owners and investors of system parts.
3. Operators of air transport.
4. Standardized Aviation municipal equipment.
5. Infrastructure ensuring flight operations:
6. Normative - legal field of System functioning.
7. Control of the technical state of the system.

3.1. The contour of consumers of aviation technology services

Consumers of urban air transport system are:

- Medical institutions of first aid;
- Burn centers and intensive care medicine;
- Emergency Situations Ministry units evacuating from areas of fire from the roofs of high-rise buildings;
- Search and rescue units of Emergency Situations Ministry;
- Ministry of Internal Affairs patrol division;
- Transportation of VIP guests;
- Tourist flights;
- Passenger transportation by sectors of the municipality.

In the process of implementing the APT system is possible phased introduction of consumers.

3.2. Contour owners and investors to parts of the system

Holders of APT system should be divided into categories:

a) Owners of aviation technology - operators.

b) The owners of landing sites and of locations.

c) Holders of labeling systems, lighting and radio support.

d) Contractors mount high-rise and high-rise buildings construction system.

e) Owners of refueling points and fuel supplies APT.

f) Owners of an information network system APT.

g) The owners of the field GPRS networks and information channels.

h) h) Manufacturers of APT system on-board hardware.

The owner of any of the components may be any investor. The priorities for the municipality of ownership may be the objects of AMT system:

- The operator;
- Landing sites and home base;
- Refueling points and APT supplies.

3.3. Operators of air transport

- Medical first aid institutions, the Ministry of Health or the operators of the contractual party;
- Burn centers and intensive care medicine;
- Emergency Situations Ministry or Emergency Situations Ministry operators contracting party;
- Ministry of Internal Affairs;
- Organization or contractual operators transport VIP guests;
- Operators of air transport;
- Private individuals.

The main operator of the municipality may be in the municipal area.

3.4. Standardized Aviation municipal equipment.

In accordance with the concept of the system of public air transport system by the aircraft can serve machines with features:

- Having FAA and JAA type certification;
- The possibility of mandatory vertical takeoff and landing;

- Dimensions of no more than 3 m (width), the X 10 m (length), the X 5 m (height);
- Maximum take-off weight up to 5700 kg .;
- scope of lifting surfaces within a radius of no more than 8 meters, D = 16 m;
- The height of the rotor carrying surface not less than 2 meters;
- At least two engines, and with the possibility of horizontal flight at an altitude of 250 meters at the failed critical engine at maximum take-off weight;
- With a maximum payload have a minimum amount of fuel on a flight of at least 2 hours;
- Static ceiling of not less than 150 m at the failed critical engine with a maximum take-off mass;.
- On-board de-icing equipment, the system;
- Automatic fire-fighting equipment and means of rescue of passengers;
- Required by the standard light-beacon and radio markings, required instrumentation Alexeiev, 2012; Alexeiev & Bondaryev, 2016).

Standardized requirements for municipal aviation technology should establish SAA.

3.5. Infrastructures ensuring flight operations

- landing sites and platforms on high-rise buildings in the city;
- home base and technical maintenance of aircraft;
- APT refueling point and expendable materials;
- light-technical and radio software sites and places of APT basing;
- light-technical and radio software of flight safety in the city;
- automated licensing system of APT production operations;
- automated control system of safe flight operations in the city;
- aeronautical and information providing of urban air transport.
- register of high-rise buildings (N = 50m and more) in Kyiv and Kyiv region .

A detailed presentation of the principles of organization of the system infrastructure is invited to present in the program.

3.6. Normative - legal field of system operation

- technical standards of aviation municipal equipment;
- requirements and standards applicable to the landing sites and systems ensuring the functioning of platforms;
- flights rules in municipal areas;
- aeronautical requirements and implementation schemes of flight routes in the municipal areas;
- training requirements for flight personnel and system of tolerances to operate in municipal areas;
- standards for building system objects in the State Building Standards (DBN);
- requirements and standards for marking, light-technical and electronic signaling systems;
- requirements for the information system of flights in the municipal area;
- regulatory support flight operations permit system in the municipal area.

Normative - legal framework is being developed the SAA. To speed up the implementation process is proposed to develop regulatory and legal aspects on a tender basis, at the announcement of the tender for these works by the SAA.

3.7. Control of the technical state of the system

- periodic monitoring of airworthiness of APT;
- continuous monitoring of readiness of flight personnel to flight operations in the municipal area;
- constant monitoring of compliance with the standard landing sites and providing take-off-landing systems;
- constant monitoring of the deviation from the technical standard of the lighting and radio engineering marking obstacles;
- continuous monitoring of the status of the information field of the system;

Regulatory control over the quality of functioning of the system should carry out SAA or organization for which were delegated these rights by the SAA.

Technical control of the functioning of the system is carried out by organizations performing technical support of the system components, including warranty conditions.

4. Sources of start-up capital and persons involved

For each element of the system start-up capital of APT can be any investment or credit of figurant. Just from the standpoint of the municipality can be seen as an investment not financial assets but assets in the form of extracted from the municipally owned system objects (landing sites, base sites, locations of refueling stations, etc.) adequately evaluated.

Each person involved determines the source of its funding of the infrastructure by themselves.

Considering that the system is able to function only in deriving the full capacity of all the elements, otherwise it simply will not work, municipality should act as a distributing entity for the selection of investors who prove their ability to participate in the project of construction of the APT system and are responsible in the case of conditions of violations contract. The head of the APT system must act its designated municipality and the authorized subdivision.

The distribution of financial sources for the construction of elements of the AMT system is determined by the Municipality, and is entered in the realization program.

5. The expenditure and revenue of the persons involved

Each person involved himself defines sources of funding to maintain its system cell, considering the costs as cost of services offered.

The revenue part has to be paid by the consumer of system services under the ordinary legislative normal deductions.

The source of income of each element of the system can be described directly in the program during the discussion with the Municipality.

6. Conclusions

At the moment the SAA has set a number of tasks for the development of regulatory and legal aspects of the system elements. But the SAA is not united these tasks in the realization problem of AMT system. Therefore, the problem is not solved in a complex and is likely the result of several problems which will not be enough for the realization of the whole system.

We must pay tribute to that international aviation legislation such activity as a municipal air transport is not regulated and is provided to address the state directly aviation authorities. But until recently, so the question was not raised at all, and therefore developments or sufficient experience in dealing with this problem in the SAA not and was not. And the question is serious due to responsibility to third parties in the event of an aircraft crash in the vicinity of the municipal buildings. Any statistical or experimental data on the specific conditions of the municipality also does not exist. It is therefore proposed realization of program of the system development carefully, cautiously in small steps, with the gradual accumulation of the necessary statistical material and sufficiently flexible regulatory - legal system. It is not acceptable for each adjustment of the rules in accordance with reality, constantly line up in the Cabinet of Ministers, the Ministry of Justice or the Supreme Council of the queue for ratification.

From a technical point of view the project has long been matured, and all technical aspects have been tested in production.

It is proposed, on behalf of the Municipality and with his direct participation to develop the "Program of development of the aviation public transport of the system of Kiev until 2015," which detail the guidelines and economic feasibility of each system element. Accordingly, to prepare material for a tender or competitive investment for the implementation of the Programme. The program will determine the tariff plan element by element, and in order to determine the profitability of the project at every stage of implementation (Alexeiev & Bondaryev, 2016; Alexeiev et al., n.d.).

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IMPLEMENTATION OF SINGLE EUROPEAN SKY: OVERVIEW OF ACTIVITIES IN SLOVAK REPUBLIC

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Abstract

Local Single Sky implementation monitoring (LSSIP) serves as a structured, localized framework that translates the high-level goals and policies of the Single European Sky (SES) initiative into actionable steps at a regional level. It is structured in such a way that it defines the specific actions required at a local level and the performance indicators that will be used to monitor progress. It is part of an integrated system aimed at improving the management of European airspace. This paper provides general characteristics of the LSSIP, including key external and internal roles, describes status of the implementation activities in Slovak republic and outlines future direction of the programme.

Keywords

Single European Sky, Local Single Sky Implementation Programme, European ATM Master Plan

1. Introduction

The SES initiative itself was introduced to overcome significant inefficiencies and safety risks inherent in Europe's fragmented air traffic management (ATM) system. The SES initiative was launched in response to delays resulting from air navigation, with the intention of reducing the fragmentation of European airspace, thereby increasing its capacity and the efficiency of ATM and ANS. The initiative is pan-European and open to neighbouring countries.

This initiative was launched in 1999 to improve the performance of ATM and air navigation services (ANS) through better integration of European airspace. Local Single Sky implementation monitoring (**LSSIP)** provides a clear plan for achieving the strategic goals of SES for local authorities. It is designed to outline the local actions and projects that contribute to the achievement of the SES targets, focusing on specific environment, airspace sectors and regional challenges. It provides a comprehensive overview of the progress made, the steps to be taken and the timeline for achieving the necessary changes.

The LSSIP ensures that local initiatives are effectively integrated into the broader SES framework, enabling stakeholders to work together to realize the full potential of the SES. LSSIP enables coordinated approach to modernization of the ATM system and allows harmonization of air traffic management procedures, technologies and policies across Europe.

The LSSIP plays a vital role in aligning local Air Navigation Service Providers (ANSPs), airspace users and relevant stakeholders with the broader SES goals, such as enhancements in the following areas:

1. Safety – minimizing risk factors in air traffic,
2. Efficiency – enhancing the throughput and air traffic flow,
3. Capacity – increasing the airspace's ability to accommodate growing air traffic,
4. Environmental Sustainability – reducing the environmental impact of air traffic operations.

Each LSSIP outlines the specific actions and projects required locally to contribute to the broader SES targets, it includes:

1. Progress Updates – tracking milestones and progress in implementing SES compliant strategies,
2. Planned Future Steps – estimating future air traffic demands and planning necessary adjustments in airspace management,
3. Timelines for Completion – establishing a clear temporal structure to ensure timely execution of the implementation phases.

From a system-level perspective, the LSSIP contributes to the SES by ensuring that local ANSPs can meet global aviation goals. By fostering **interoperability, data exchange and collective operational standards,** the LSSIP facilitates a more efficient and unified air traffic system. This helps to minimize inefficiencies, reduce costs, and improve the environmental performance of the entire European aviation network.

2. Characteristics of LSSIP

The LSSIP documents provide an extensive, consolidated and harmonised picture of how ECAC States and States having a Comprehensive Agreement with EUROCONTROL, and stakeholders concerned, are progressing in planning and deploying all mature elements of the European ATM Master Plan.

2.1. Key External Roles

States, through their National Regulatory Authority (NSA, CAA) have multiple responsibilities in relation to the implementation of appropriate functionalities while building and further developing the European ATM system.

The National LSSIP Focal Point (FP) is a person nominated by the State. The Focal Point is responsible for the coordination of all national Stakeholders during the production of the LSSIP document of the State and ensuring correct and consistent LSSIP data by respecting the agreed time schedule.

The LSSIP Expert Group (LSSIP EG) is established to further enhance the involvement of LSSIP Focal Points / Experts in the development of elements of the LSSIP, e.g. operational matters, process, guidance material, tools, ways of working (including collection and sharing of best practices, lessons learnt, etc.).

2.2. Key Internal Roles

The LSSIP Contact Person (further CP) supports the LSSIP cycle (preparation, execution, maintenance) by mediating between EUROCONTROL and/or SDM and the State to achieve timely, quality and correct formatting production of the LSSIP document. The CP provides the necessary support, instructions and guidance to his/her State(s) for the production/update of the LSSIP and related activities. The CP works in support of the National Focal Point who is responsible for providing consistent and complete LSSIP information.

The LSSIP Objective Coordinator (OC) supports the LSSIP cycle (preparation, execution, maintenance) by mediating between the CPs and the EUROCONTROL Experts. OC works in close cooperation with the EUROCONTROL Experts and the SDM Coordinators and provides feedback to the CPs for the Data Cross Check Period.

SDM Coordinators are involved in SESAR Deployment Programme (SDP) monitoring. They are in charge of elaborating the SDP Monitoring View and the Risk Management Plan based on the yearly SDP Monitoring Exercise performed via EUROCONTROL LSSIP+ tool.

The SDM technical experts are grouped per CP1 ATM Functionality (AF) and represent the main reference for the technical guidance related to CP1 / SDP Families.

2.3. LSSIP Process Related Definitions

Initial Draft

It is the first version of the LSSIP document produced by the LSSIP Support, uploaded on the LSSIP SharePoint after the LSSIP Event. The document consists of all chapters, text and graphics based on the previous year's final version.

Objectives Stabilization & Database Blocking Date

After this day the database is blocked for all Focal Points for any further editing of the Implementation Objectives and Questionnaires. If changes are required after the Database Blocking Date, the FP may communicate those changes to the CP, who then can process the request and update the DB (if relevant).

Data Cross-Check Period

The period between Database Blocking Date and Freezing of the LSSIP+ Database Date. EUROCONTROL and SDM Experts will check all the objectives and questionnaires. All the necessary potential amendments will go through the Change Request Procedure.

Change Request Procedure

Specific procedure that is applied, if the change of data in the LSSIP+ Database is needed after Database Blocking Date. During two weeks after Database Blocking Date, the relevant CP will input the Change Requests for States according to the comments received from the consulted Experts. The FP provides feedback on the received CRs before the freezing of the LSSIP+ Database Date. In the LSSIP+ Database the CRs can only be closed by the CP.

Freezing of the LSSIP+ DB Date

The day of the year when LSSIP+ Database is frozen for any changes by FP or CP. From this moment, read-only access is provided to all experts. Projects remain open for two more weeks. The number of projects and their names shall not be modified after the freezing of the LSSIP Database Date. Description of the scope and the progress of the projects can be updated.

Working Level Agreed (WLA)

The version of the LSSIP document in which all Chapters and all Annexes have been fully updated by the FP and the CP. This version will not change anymore, except for editorial corrections related to spelling mistakes, formatting etc. The State shall reach this version by end of March at the latest and shall use it for the signatures.

3. Overview of activities in Slovak Republic

The LSSIP of the Slovak Republic contains 87 main objectives (out of which 32 are not applicable) with different status of completeness (as depicted by Figure 1 and Figure 2).

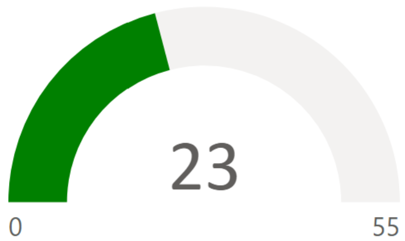

Figure 1. Number of completed objectives in Slovak Republic as of 2023 Source: EUROCONTROL (2023).

Note: Not Applicable Objectives are excluded from the count

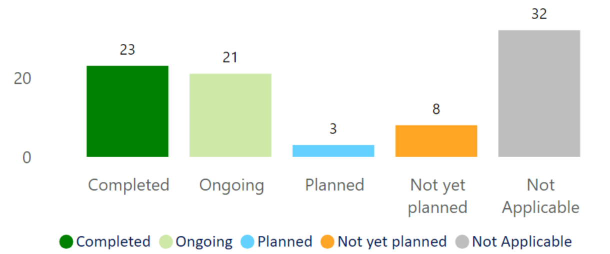

Figure 2. All LSSIP Objectives by status. Source: EUROCONTROL (2023).

The LSSIP in the Slovak Republic is governed by the following timeline (Figure 3, Figure 4).

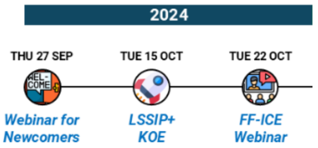

Figure 3. Timeline of the LSSIP in the Slovak republic for 2024. Source: EUROCONTROL (2024).

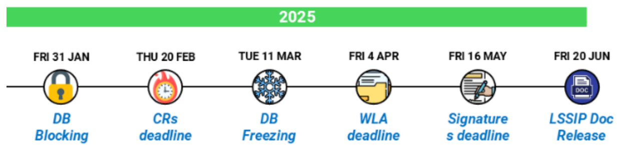

Figure 4. Timeline of the LSSIP in the Slovak republic. Source: EUROCONTROL (2024).

<u>Note:</u> CR – Change Request; DB – Database; FF-ICE – Flight and Flow Information for Collaborative Environment; KOE – Kick-off Event; WLA - Working Level Agreed

3.1. LSSIP drawbacks

1. Misunderstanding – the current system for filling and implementation of the main objectives and the local objectives allows different interpretations. There is no clear explanatory material available.

2. High number of experts involved in the process – coordination of meetings is demanding and time consuming.

3. Complexities in text consolidation - many instructions, notes and information how to report the progress of implementation, how to fill-in the reporting information, how to extract the data, how to understand warnings, etc.

Member States must be precise and careful when filling the LSSIP in. In case of misinterpretation, especially in case of non-compliance, there is a possibility of infringement procedures against the member state.

4. Future Direction

The future Air Traffic Management (ATM) system needs to accommodate new types of airspace users, ranging from drones to all different types of new aircraft. The ATM system of the future will rely much more heavily on digital technologies and systems than today. This inevitably means that data and system security become ever more important in relation to the ATM system.

To cope with the future demand, Europe needs a more network-centric service delivery model. In the future, Air Traffic Flow Management (ATFM) will evolve to support the management of complete traffic flow in the network context and in a collaborative manner.

The fulfilment of the Single European Sky (SES) objectives is expected to underpin the whole process of modernising the European ATM system. The Slovak Republic should have most of the SES targets met by 2030 (as shown in Figure 5).

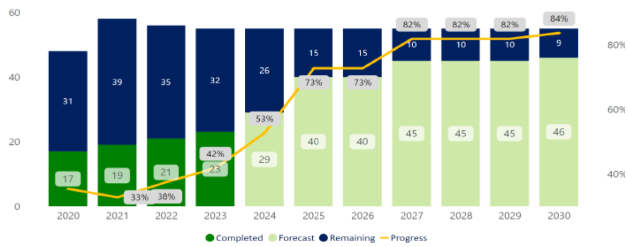

Figure 5. Expected objectives completion evolution until 2030. Source: EUROCONTROL (2024).

5. Conclusion

The LSSIP process aims at monitoring of the Implementation of the Objectives described in the EUROCONTROL Implementation Plan and Report (EIPAR) and other linked implementation activities at State level on a yearly basis. Operational Stakeholders (ANSPs, Airports Operators, MET Service Providers, Civil Aviation Authorities, Military Authorities) are called to report on the progress of their local implementation plans at the end of each calendar year.

The LSSIPs contain the detailed national plans and local implementation actions required to achieve the objectives and to meet national performance targets, safety improvements and capacity profiles identified. They provide the means to monitor and report on the progress of local actions.

The outcome of this activity is the national LSSIP Document, which aggregates the status of implementation of the National Stakeholders at the end of the calendar year.

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